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Exploring Effects of Sequencing Modes towards Logistics Target Achievement on the Example of Steel Production

K. Windt^{a,*}, P. Nyhuis^b, O. Herr^a^a*School of Engineering and Sciences, Global Production Logistics, Jacobs University Bremen gGmbH, Campus Ring 1, 28759 Bremen, Germany*^b*Institute of Production Systems and Logistics, Leibnitz University Hannover, An der Universität 2, 30823 Garbsen, Germany** Corresponding author. Tel.: +49-421-200-3478; fax: +49-421-200-3078. E-mail address: k.windt@jacobs-university.de

Abstract

The objective of this paper is to discuss the logistics target conflict of achieving both low set-up costs and high due-date reliability. We are introducing first approaches towards a methodology dealing with this target conflict which enables a strategic positioning on behalf of new Sequencing Operating Curves. Based on an industry case study in the steel industry, we are describing the problem of batching and sequencing under highly demanding technological constraints. Analysis based on industry data display the extent of the described problem in practice.

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1. Introduction

The steel production process is characterized by high capital expenditures for production equipment [1] [2]. Therefore large throughput to reduce the costs per produced unit is the central production objective. At the same time the competitive environment has changed. European steel manufacturers face increasing pressure from Far East producers. In order to compete on the market, they need to offer a greater variety of high quality products with a strong focus on customer wishes [3]. Due to strong integration into the customers' supply chains, reliable delivery of finished products becomes more and more important [4] [5]. As a result of the above-mentioned changes in the market, the focus of European steel manufacturers tends to move from costs towards quality and delivery performance, especially achieving higher delivery reliability. Production logistics, respectively production planning and control (PPC), has a major impact on these targets and therefore on the competitiveness of a company [6].

The process of steel production is organized as a flow shop with multiple stages. Each stage has highly

differing requirements regarding the production sequence [1] [6]. The resulting scheduling problem is too complex for all local constraints to be respected within one planning procedure [7]. Therefore, production planning in steel production is executed in hierarchical planning levels. Each planning level deals with only part of the given constraints [8]. In the higher planning level, the customer orders are scheduled into certain planning periods (PP). Based on the resulting schedule, delivery dates are communicated to the customers. Within lower planning levels, the actual sequence is decided by taking all detailed requirements of the individual production stage into account. Although much effort has been undertaken to improve the distribution into PPs on higher planning levels, orders are still grouped together from different PPs within lower level sequencing. The motivation for grouping orders can either have a technological background (e.g. minimum lot-sizes in batch production) or can be undertaken in order to reduce the amount of set-ups, therefore, raising the productivity on the expensive production resources. In the latter case, it is chosen to improve the logistics cost target on the expense of the logistics performance target (due date

reliability). The effects of different sequencing decisions have not yet been quantified. Therefore no strategic decision on balancing these conflicting targets is possible.

The aim of this paper is to demonstrate that the described sequencing problem exists in industry and to introduce a new methodology (Sequencing Operating Curve) to deal with conflicting targets in short term sequencing. The paper is structured into four sections. Following the introduction, section two describes the logistics objectives and the connection to PPC. In section three the Sequencing Operating Curve is introduced. Section four contains a detailed description of the trade-off and displays results from an industry case study, demonstrating the identified research question.

2. Logistics targets and the influence of production planning and control

The targets of production logistics can be split into logistics costs and logistics performance [10]. The logistics performance of a production system is determined by the ability to meet the customer's expectations in terms of time. That includes short delivery times, high delivery capability (ability to meet the desired delivery date) and high delivery reliability of the committed date [9] [11] [12]. Lateness, calculated as the difference between the completion date and the due date (delivery date), is a commonly used measure to assess the reliability of logistics performance [9] [12]. The objectives delivery reliability and delivery time can also be assessed for each operation within the production process. In that case, reliability is measured using the scheduled due date of the operation and delivery time is substituted by the throughput time of the single work system. In this paper we will use the average and standard deviation of lateness to access the due date performance. On the other side, logistics costs can be divided into tied-up capital costs of work in process inventory and production unit costs (usage of capacities in terms of throughput per period) [9] [10]. The latter is especially relevant in batch production, where major set-ups are necessary to change between different product types.

The described logistics targets achievement is determined by the quality of performing PPC tasks. PPC can be separated into various subtasks and different planning horizons (usually long, intermediate and short). There are different approaches to depict the relationships of the included task. For example, the Aachener PPC-Model founded by Eversheim and Luczak [11] or models based on Manufacturing Requirements Planning (MRP-II) [9] [14].

All models start with a long-term planning based on forecasting where cornerstones are determined (e.g. production program, long term capacity dimensioning). On a mid-term planning level, the customer orders are converted into capacity demands for each production resource. A production plan is established using various planning subtasks (e.g. scheduling, capacity requirements planning and lot-size calculations). Mid-term production planning has a large impact on the logistics target achievement. At this point, trade-offs between the different targets exist (e.g. low work in process vs. high utilization) and the goal is to find a beneficial balance between them [9] [12]. The mid-term planning can create the conditions for high logistics targets achievement. But only when the plan is executed without severe deviations, the potentials can be exploited. SCHUH states that the task of production control is to decide about the actual production sequence based on the specifications from production planning and the logistics targets [11]. Effective control methods are required in order to generate high logistics target achievement [13]. In this paper we will discuss the task of detailed production planning (henceforth referred to as sequencing) which consists of determining the actual production sequence for a production stage and therefore can be considered as a production control task. In case batching decisions also occur during short term sequencing, a trade-off between set-up costs (usage of capacity and changeover costs) and due date reliability arises. This trade-off is further discussed in the following section.

3. Introduction of the Sequencing Operating Curve

Our goal is to develop a tool which enables production planners to find a strategic positioning between the described contradicting logistics targets. As logistics operating curves according to Wiendahl and Nyhuis have proven as powerful positioning tools we will continue to develop sequencing operating curves [12].

In case major set-ups are necessary when producing different product types, the sequencing decision for a work system consists of batching a certain amount of orders needing the same set-up configuration together and determining the sequence of the different set-up families. Each decision can be done using dispatching rules or in more complex environments, like in steel production, be executed in manual heuristic procedures.

A sequencing procedure that strictly chooses the largest set-up family and produces all orders available even in long term planning horizon for that family, will assumingly lead to few set-ups, and therefore low changeover costs and high capacity usage (throughput) of the work system. In case that not all orders of the

largest set-up family are due and orders from smaller set-up families are already overdue, this procedure will lead to lateness (positive and/or negative) due to orders shifted forward and orders being retarded. The result is a low due date reliability. This procedure can be classified as cost oriented. On the other side, a sequencing procedure can be strictly focused on due dates. Choosing set-up families according to their urgency will most likely minimize the lateness of orders. At the same time assuming the same product type distribution more changes between the different set-up families are necessary, resulting in greater changeover costs and less capacity usage (throughput). This procedure can be classified as due date oriented.

Fig. 1 displays the expected dependencies. On the x-axis, the different alternatives for sequencing will be depicted. The scale reaches from a cost optimal sequencing to a due date optimal sequencing. The red curve shows the anticipated effects of the different sequencing procedures on the capacity usage

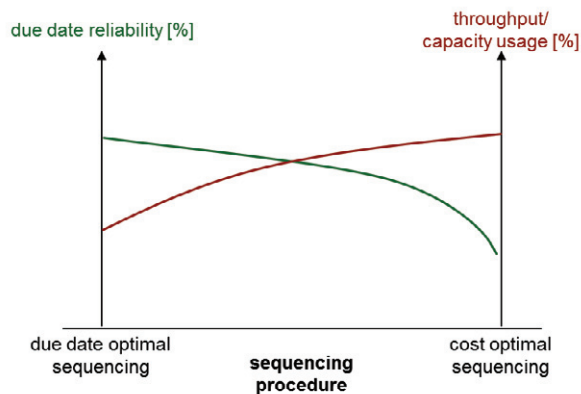


Fig. 1. Sequencing Operating Curve

(throughput), changeover costs are not displayed. The green curve shows the expected effects on the due date reliability. The more a sequencing procedure tends towards cost optimal production (away from due date optimal production), the higher will presumably be the throughput or capacity usage and the lower will be the due date reliability. The exact slope of the curves will be decisive in order to decide, which amount of throughput reduction one has to accept for increasing the due date reliability to a desired degree.

If the concerned work system is identified as a bottleneck, another aspect has to be considered. The capacity usage of a bottleneck work system has an impact on the total throughput per period. A sequencing procedure that focuses on due dates could lead to a large amount of set-ups and therefore reduce the throughput. This means that fewer orders can be produced within a certain PP and consequently more orders have to be postponed. Therefore extreme due date orientation can actually have a negative impact on the due date

reliability target (this aspect is not displayed in Fig. 1). Also, the impact of capacity control on the curves has to be investigated.

Knowing the overall effects of different sequencing procedures, managers can decide upon a targeted area where contradictory objectives are balanced according to the current market requirements. The targeted area serves as parameter default for those who are responsible for sequencing. This way the management can decide upon the procedure used for sequencing and is less dependent on the individual knowledge and experience of employees. In the following chapter we will discuss this problem on behalf of the example of steel production.

4. Describing the conflict on behalf of steel production

4.1. The steel production process and the resulting challenges for the task of production planning and control

The steel production process usually consists of the stages iron making, steel making, continuous casting, hot strip milling, pickling, cold roll milling and refinement processes such as annealing, temper milling and coating.

According to the final product, all, or parts of these stages have to be traversed in a specific production mode. Each stage has highly differing requirements on the sequence of orders to be produced [1] [6]. For the casting process, orders have to be grouped according to steel grade and similar widths. Hot strip milling requires a specific sequence with only gradual changes in slab width and gauge in order to achieve the necessary quality. Within the coating stage, orders again have to be grouped together with respect to the demanded coating type. Planning orders according to the requirements of the continuous casting stage will most likely not fit the constraints for sequencing at the hot strip milling stage and vice versa. The grouping requirements of the coating stage also add to the complexity of the planning task: A simultaneous planning respecting the detailed requirements of all production stages is not applicable [7]. In order to cope with these difficulties, production planning and control in steel production is executed in hierarchical planning levels [7] [8]. On a more general, higher planning level, customer orders are transferred into production orders, where the required production stages and operations are specified. Furthermore, the production orders are scheduled into certain PPs (e.g. daily, weekly) for each production resource. Due to the described complexity of differing technological requirements throughout the production stages, the detailed production sequence is not part of this rough planning level.

Different approaches have been developed to distribute the production orders into the PPs on the higher planning level [7] [8]. Based on this, delivery dates are communicated to the customers and due dates are set for each order on the different production stages. The result of the higher planning level is a set of orders for each PP and production resource that serves as input for lower level, detailed planning. Within this level, the actual sequence of production orders is determined for every machine at each production stage. This is established using individual sequencing procedures for each production stage to handle the complex technological requirements [7] [16].

In the optimal case, only the orders distributed into a certain PP of a production stage are used to generate the actual production sequence. A problem occurs when orders within a certain PP are not applicable to generate a satisfactory sequence. This is due to the explained circumstances that detailed restrictions are not considered sufficiently during the distribution of orders into PPs (higher level planning). As a consequence, the planner has to use orders from other PPs to generate the production program. This procedure causes orders to be early when pulled from a subsequent PP or to be postponed when pulled from a preceding PP. Since the due dates are defined on the higher planning level, deviations from the planned period lead to earliness respectively lateness. Fig. 2 depicts the arising conflict of objectives.

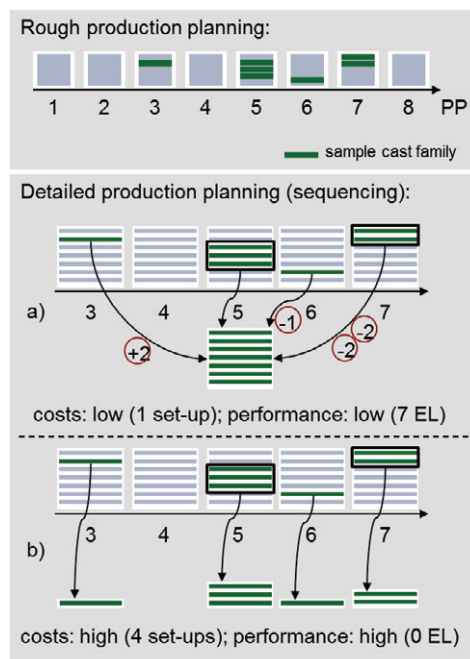


Fig. 2. Conflict of cost and performance objectives in detailed production planning (sequencing)

Orders requiring the same set-up state (displayed as green bars) were scheduled within rough production planning into the PPs 3,5,6 and 7 for a given production stage. The sequencing procedure a) tends to cost optimal production and groups all orders from the different PPs together in one period (in the example presented here that is PP 5). This leads to only one set-up process but at the expense of resulting positive lateness of 2 PPs and negative lateness (early) of 5 PPs. The lateness, either positive or negative is depicted within the red circles of Fig. 2. The sequencing procedure b) is strictly fulfilling the schedule (due date oriented) and produces neither lateness nor earliness. This can only be achieved when four set-up processes are undertaken.

The described decision for an individual set-up family is only part of the sequencing task. The conflict between cost-optimal and due-date-optimal production also arises in the selection of set-up families to be produced within a certain PP. As the available capacity for each PP is limited, the different set-up families compete against each other. Set-up families with small demand, even when grouped together, will require more overall changeovers than set-up families with high demand that can be produced in big lot sizes. In this decision, a sequencing procedure focusing on costs will choose set-up families that enable big lot sizes leading to few changeovers while the due dates of small set-up families are neglected.

4.2. Quantifying the problem for the continuous casting stage

The continuous caster is fed with ladles of molten steel of the same grade (metallurgic specification). The size of a ladle can vary but is usually fixed for a certain caster (e.g. 300tonnes). The molten steel within one ladle is called heat and represents the smallest unit that can be produced. The heat is poured into the tundish of the caster, which serves as a buffer for the casting process allowing multiple heats to be produced consecutively. This is only possible for heats belonging to the same cast family. Similar steel grades with overlapping tolerances of chemistry and temperature are clustered into cast families (castable grade families) [15]. In case of differing cast families, set-up costs arise in terms of e.g. opportunity costs (when the caster is stopped or slowed down), labor costs, tundish replacement costs or downgraded slabs at the beginning and end of each sequence (deteriorated steel quality). The set of heats produced consecutively is called a production sequence. The amount of heats represents the length of a sequence. From the tundish, the molten steel flows into the mould where it solidifies. The dimension of the slabs is set by the size of the mould, which can be adjusted only to a certain extent. Therefore, only slabs

with similar width requirements can be casted together in one heat. The fire-resistant coating of the tundish has to be replaced after a certain amount of heats, limiting the total number of consecutive heats, thus the sequence length [15] [16].

The overall due date performance of the observed continuous casting stage can be analyzed using a histogram of the orders' lateness. Fig. 3 displays the output lateness for the orders produced within the period of examination. The numbers have been scaled in order to assure confidentiality.

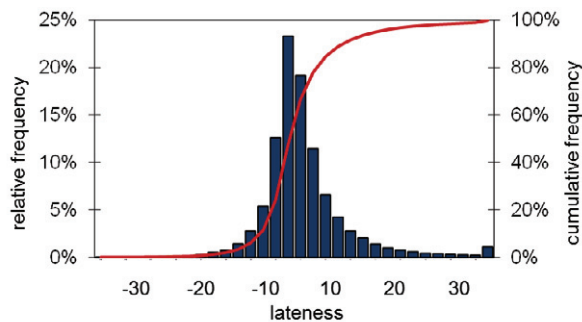


Fig. 3. Lateness of orders for the continuous casting stage (arbitrary numbers)

The figure supports the assumption that steel production sequencing is primarily focusing on cost optimization on the expense of due date performance. The schedule adherence is approximately 50% and only 23% are produced exactly within the planned period from higher level planning.

4.2.1. Analyzing the individual cast families

In order to assess the degree of grouping (batching), we compare the frequency of planning with the frequency of production for each cast family. To reduce the complexity in this first analysis, only the steel grade will be used to differentiate between the cast families. The frequency of planning is calculated on the basis of the work contents planned for each cast family within the different PPs, the frequency of production analogically on the basis of work contents produced over the PPs. The coefficient of variation, calculated as the quotient of average planned/produced work content and standard deviation of planned/produced work content, displays how frequently a cast family is planned/produced. A low coefficient of variation indicates that a cast family is planned/produced very regularly in terms of distribution into PPs and the quantities planned/produced. The coefficient of variation is high when the demand for a specific cast family is planned/produced irregularly over the PPs. By comparing these two measures the grouping amount can be analyzed. For this purpose, the coefficient of variation

of planning is divided by the coefficient of variation of production. We call the resulting measure the Ratio of Variation (RoV). A RoV with a value less than one indicates that the cast family is planned more regularly than it is produced. Equal frequencies of planning and production result in RoV around one and infrequent planning with frequent production is displayed by RoV greater than one. Fig. 4 depicts the RoV for the different cast families. Only cast families, planned and produced in more than one PP are considered.

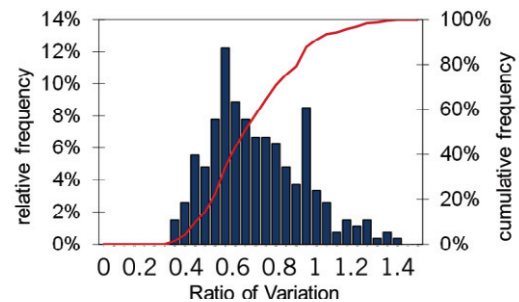


Fig. 4. Ratio of Variation (RoV) between planning and production

Fig. 4 highlights that for 80% of the cast families the RoV is less than one, for 9% the RoV is around one and 11% are characterized by a RoV above one. The average RoV is 0.73 with a standard deviation of 0.23. The large amount of cast families with RoVs less than one points out that in the majority, cast families are more frequently planned than they are produced. This is a strong indicator that orders planned in different PPs are produced together and the described grouping in section 4.1 is present in the industry case study.

4.2.2. Analyzing the aggregated sequencing decision

The second aspect of sequencing concerns the aggregated decision of selecting cast families for a specific PP. As described the aim is to serve both targets: high throughput and high due date reliability based on given customer orders. The tradeoff situation enforces an adequate positioning of target achievement. In order to assess the executed sequencing decision in the analyzed industry case study, we are comparing the mean and standard deviation of lateness. Fig. 5 displays the frequency of the sequence length and the described performance measures. The numbers have been scaled to assure confidentiality.

Fig. 5 underlines the focus on large sequences. One third of all sequences were produced with the maximum sequence length. The average lateness (number above bars) of small sequences is clearly higher than for long sequences. In the aggregated sequencing decision, these belated small sequences compete with longer sequences with lower lateness. As assumed, the executed

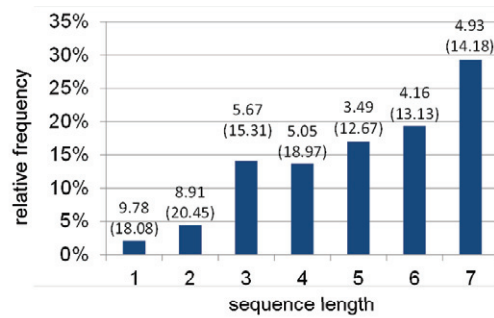


Fig. 5. Distribution of sequence length

sequencing procedure in the steel industry is focusing on cost optimization and longer sequences that are less belated or preferred over small belated sequences. The standard deviation of lateness (number in brackets over bars) is a sign for the range in which orders were grouped together. It could be assumed that large sequences result in high standard deviations as a result of grouping orders together. The opposite can be observed. This is due to specific cast families with large demands in every PP. These cast families are produced in large sequences with only little lateness, influencing the displayed performance measures.

Both analyses show that the problem of balancing set-up costs and due date reliability is present in the industry case study. The assumption that a strong focus in steel production is set on cost reduction due to expensive production equipment was confirmed in general.

5. Conclusion and Outlook

The purpose of this paper was to highlight the conflict between the logistics targets due date reliability and set-up costs within sequencing. On the example of a case study with a European steel manufacturer, we wanted to analyze the relevance of the problem for the practice.

We introduced the so-called Sequencing Operating Curve (SOC) as a new tool to fulfill the positioning between the described conflicting logistics targets. The idea is to classify different sequencing procedures on a scale reaching from cost optimal sequencing to due date optimal sequencing. We are currently working on a measure to perform the classification.

We pointed out that the steel production process is highly complex in terms of production planning. Due to varying technological requirements on the different production stages in combination with a high number of product variants, a large part of sequencing is done on lower level planning. On the example of the continuous casting stage, we described the problem in detail for an industry case study. Further, we demonstrated that the theoretical problem exists in practice. A strong focus on set-up cost reduction on the expense of due date performance was observed in the industry case study. As

due date performance becomes increasingly important in the steel market, a methodology like the introduced Sequencing Operating Curve will help in positioning between the conflicting targets with respect to market requirements.

The extent of the described problem was only shown on the example of one case study in the steel industry. Further studies are necessary to gain an overview of possible fields of application for the, to be developed Sequencing Operating Curve. Possible impact factors, like the structure of orders to be scheduled and capacity control, were mentioned in this paper. In future research, these impact factors have to be investigated.

References

- [1] Ouelhadj, D. A multi-agent system for the integrated dynamic scheduling of steel production, PhD Thesis, School of Computer Science and Information Technology, Nottingham University, 2003.
- [2] Tang, L., Liu, J., Rong, A., Yang, Z. A review of planning and scheduling systems and methods for integrated steel production, *European Journal of Operational Research*, 133, 1-20, 2001.
- [3] Labitzke, N., Volling, T., Spengler, T.S. Wertorientierte Simulation zur Unterstützung der logistischen Prozessgestaltung bei der Stahlherstellung, *Zeitschrift für Betriebswirtschaft*, 81, 771-803, 2011.
- [4] Cowling, P.I., Ouelhadj, D., Petrovic, S. A multi agent architecture for dynamic scheduling of steel hot rolling, *Journal of Intelligent Manufacturing*, 14, 457-470, 2003.
- [5] Denton, B., Gupta, D., Jawahir, K. Managing Increasing Product Variety at Integrated Steel Mills, 33/2, 41-53, 2003.
- [6] Cowling, P.I., Rezig, W. Integration of continuous caster and hot strip mill planning for steel production, *Journal of Scheduling*, 3, 185-208, 2000.
- [7] Voß, S., Witt, A. Hybrid flow shop scheduling as a multi-mode multi-project scheduling problem with batching requirements, *International Journal of Production Economics*, 105, 445-458, 2007.
- [8] Vanhoucke, M., Debels, D. A finite-capacity production scheduling procedure for a Belgian steel company, *International Journal of Production Research*, 47/3, 561-584, 2009.
- [9] Hopp, W.J., Spearman, M.L. *Factory Physics*, Irwin/McGraw-Hill, Boston, 2008.
- [10] Wiendahl, H.-P. *Betriebsorganisation für Ingenieure*, Hanser, Munich, 2008.
- [11] Schuh, G., *Produktionsplanung und -steuerung*, Springer, Berlin, 2008.
- [12] Nyhuis, P., Wiendahl, H.-P. *Fundamentals of Production Logistics*, Springer, Berlin, 2008.
- [13] Löffding, H. *Verfahren der Fertigungssteuerung*, Springer, Berlin, 2005.
- [14] Schönsleben, P. *Integral Logistics Management*, Auerbach Publications, New York, 2007.
- [15] Box, R.E., Herbe, D.G. A Scheduling Model for LTV Steel's Cleveland Works' Twin Strand Continuous Slab Caster, *Interfaces*, 18, 42-56, 1988.
- [16] Lee, H.S., Murthy, S.S., Haider, S.W., Morse, D.V. Primary production scheduling at steelmaking industries, *IBM Journal of Research and Development*, 2, 231-252, 1996.